

# Influence of Water Table and Peat Thickness on Dissolved Organic Carbon of Tropical Peat Soil with Sulfidic Substratum from Central Kalimantan, Indonesia

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## Abstract

Peatlands are important due to their high carbon storage, their role in suppressing climate change processes, and their importance for local and global communities' livelihood. Large amounts of organic carbon pools in peatlands can be released into the environment as gaseous emitted carbon and lost through waterways (fluvial). The carbon released through the water stream consists of organic and inorganic forms and is partly in the form of CO<sub>2</sub> and CH<sub>4</sub> gases. The organic form consists of dissolved organic carbon (DOC) and particulate organic carbon, where DOC is the most dominant organic carbon in water sourced from peatlands. This research's objectives were to study the DOC concentration of peat water resulting from the hydrological condition's difference and the peat thickness overlaying the sulfidic substratum. The study was carried out in the Pangkoh area of Pulang Pisau district of Central Kalimantan. Peat water is taken on PVC pipes installed on each plot representing different peat thicknesses (deep, moderate, and shallow peat) at a depth of 25, 50, 100, 150, 200, and 250 cm from the soil surface. The water sampling was conducted on the peak wet season, during the transition from wet season to dry season and during the peak dry season. The results showed that DOC was influenced by peat thickness, depth of sulfidic material, and groundwater level. The release of DOC is higher from the deep peat than from the thin and moderate peat. The difference in DOC concentration between peat thickness is also related to the electrical conductivity of the peat water. The results showed a negative correlation between electrical conductivity and DOC concentration. The negative correlation was significant in the observation of the rainy and dry seasons, while in the transitional season, it was not significant.

**Keywords:** dissolved organic carbon, pyrite, tropical peat, water table

## 1. INTRODUCTION

Peatlands cover a third of global wetlands [1] and they are important ecosystems for biodiversity conservation, climate regulation, and human well-being [2]. Peatlands are characterized by the build-up of organic matter from dead and decaying plant debris in water-saturated conditions. Of the total world peatland area of around 400 Mha [3], as much as 31–46 Mha or about 10–12% are in tropical areas [4]–[6]. More than half (24.8 Mha) of global tropical peatland is located in Southeast Asia (56%), mostly in Indonesia and Malaysia. The Indonesian tropical peatland area is estimated to be 13.43 Mha [7]. Due to the considerable thickness (average > 5 m) of peat soil in these two countries,

they contain 77% of the total carbon storage of tropical peat [4]. Carbon stocks stored in tropical peatlands range from 50 to 105 GT or 11–14% of global carbon stocks [8]. In South East Asia, the largest tropical carbon stock is found in Indonesia's peatlands, which is 57.4 Gt carbon or the equivalent of 65% of total tropical peat carbon [4].

Large amounts of organic carbon pools in peatlands are possible to be released into the environment as gaseous emitted carbon and lost through watercourses (fluvial) [9]. The carbon released through the water stream consists of organic and inorganic forms and is partly in the form of CO<sub>2</sub> and CH<sub>4</sub> gases [10]. The organic form consists of dissolved organic carbon (DOC) and particulate organic carbon (POC), where DOC is the most dominant organic carbon in water sourced from peatlands [11]. DOC is operationally defined as the fraction of organic carbon having a diameter of less than 45 µm [12]. DOC concentrations in natural peat range from 3 to 400 mg L<sup>-1</sup>, with an average of 30 mg L<sup>-1</sup>, and DOC exported from peat is 5–40 g m<sup>2</sup> year<sup>-1</sup> [12][13]. Loss of DOC is important in determining the carbon balance of peatlands [13][14]. Ecologically and geochemically, DOC plays a role in influencing acidity, nutrient availability, and metal mobility of ecosystems in the

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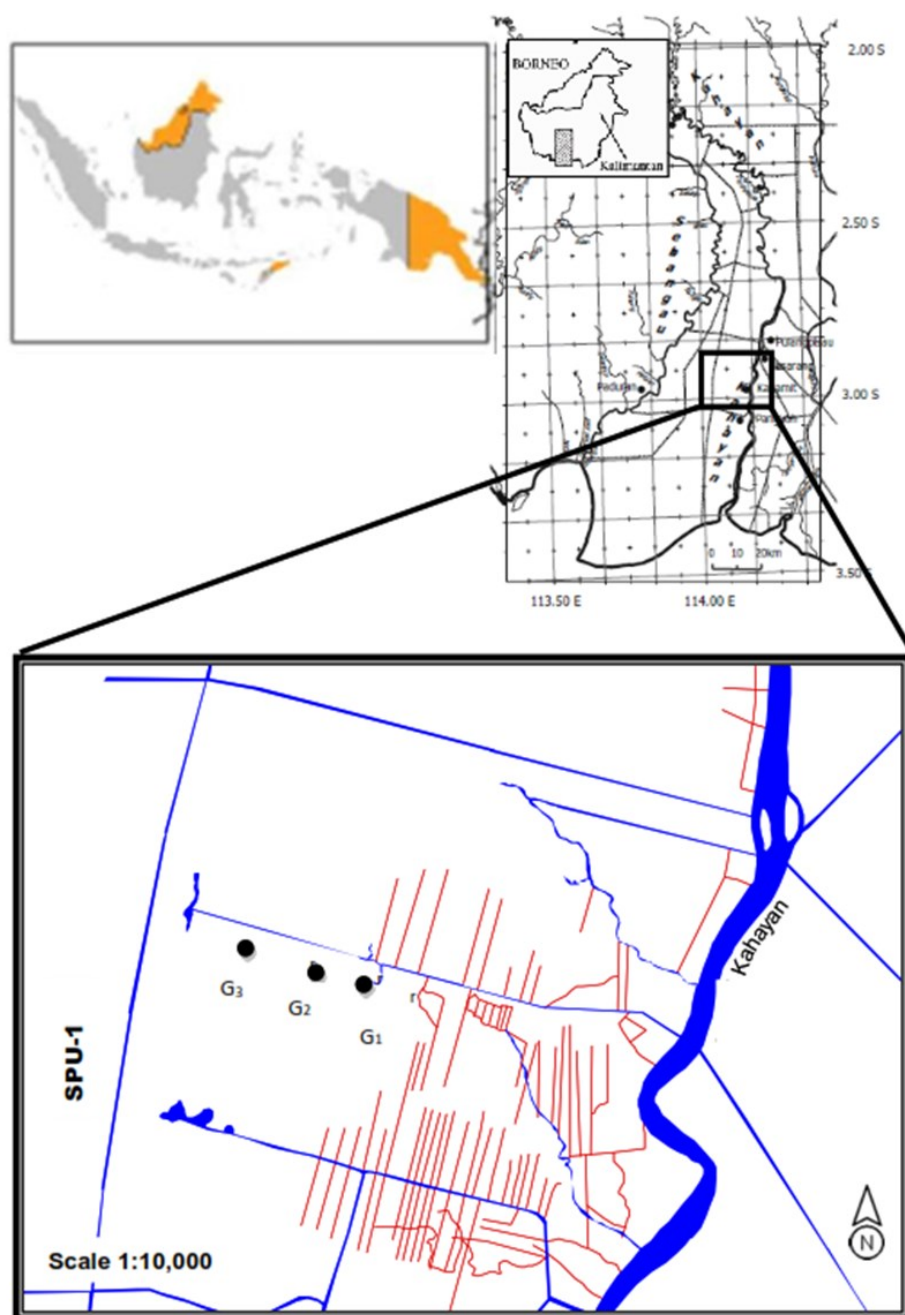
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**Figure 1.** Research locations and observation plots (G1 = shallow peat, G2 = moderate peat, and G3 = deep peat).

peatlands' downstream area [15]. The results showed that hydrological conditions were one of the main factors affecting the production and loss of organic carbon through water flow in peat soils [16]–[20]. However, only a few studies have been conducted on tropical peatlands [21]–[27]. There is not much data regarding the dynamics of DOC on tropical peatlands and the factors that influence it. Thus, this study aimed to determine the effects of the water table on the DOC concentration of tropical peat soils with different peat thicknesses.

## 2. MATERIALS AND METHODS

### 2.1. Study Site

The research was conducted in the Pangkoh IX area, Central Kalimantan, which is in the Block C of the former EX Mega Rice Project, Indonesia. The research location is located between the Kahayan River and the main primary channel (MPC -1) ex-MRP with a position at S 2°52'19.00" – S 2°53'06.80" and E 114°05'34.54" – E 114°07'00.96" with an elevation of about 8 m above sea level

(Figure 1).

The research area consists of the alluvial quarter (Qa) formation which was formed since the Holocene. The Qa formation is composed of kaolinite clay and silt interspersed with sand, peat, loose pebble and gravel, as river, swamp and marine deposits. Clay deposits in the marine environment are generally mixed with pyrite and form sulfidic materials [28].

The land use in each research site respectively are non-intensive rice fields (shallow peatlands), rubber plantation (moderate peatlands), mixed vegetation of shrubs, and Meranti deep peatland (*Shorea* sp.). The soils in research sites are classified as peat/organic soils. Soil classification according to Soil Survey Staff [29] found that the sampling location is variated from Terric Sulfisaprist, Typic Haplosaprist, and Hemic Haplosaprist.

## 2.2. Peat Water Sampling

Peat water samples were taken using a hand pump made of a syringe with a hose attached to the PVC pipes that were installed in each plot representing different peat thicknesses at a depth of 25, 50, 100, 150, 200, and 250 cm from the ground (Fig. 2). Each depth represents a peat water sample at a certain depth. The coordinates of the sampling points are shallow peat (<100 cm) (S 2°52'6.29" and E 114°06'0.88"), moderate peat (100–200 cm) (S 2°52'372" and E 114°05'881 and deep peat (> 200 cm)

(S 2°52'240" and E 114°05'409"). Sampling was conducted three times a year during the two years of the study. The sampling times are January, which is the peak of the rainy season, May, the transition from the rainy season to the dry season, and September, which is the dry season's peak. The timing of sampling is based on rainfall data at the research location.

## 2.3. Sample Preparation and Analysis

Immediately after sampling, all samples were filtered through a pre-rinsed 0.45 µm filter membrane (Whatman ME 25/21 ST) and aliquots were stored frozen in muffled glass ampoules or polyethylene bottles for the analysis of DOC. Samples were analyzed on a high-temperature combustion method with a Fusion Total Organic Carbon (TOC) Analyzer <sup>TM</sup> (Teledyne Tekmar), with a detection limit of up to 0.2 ppb which was carried out at the Jenderal Soedirman University Research Laboratory, Purwokerto, Indonesia. The DOC concentration measurement stage using a TOC-analyzer (Teledyne Instruments) is a DOC combustion process with a temperature of 680°C to be converted into CO<sub>2</sub> gas then a nondispersive infrared (NDIR) sensor will directly correlate it as the DOC concentration. A four-point calibration of the total organic carbon analyzer was performed with standards made from Fisher-certified potassium hydrogen phthalate (Fisher Scientific). Before injection into the total organic carbon

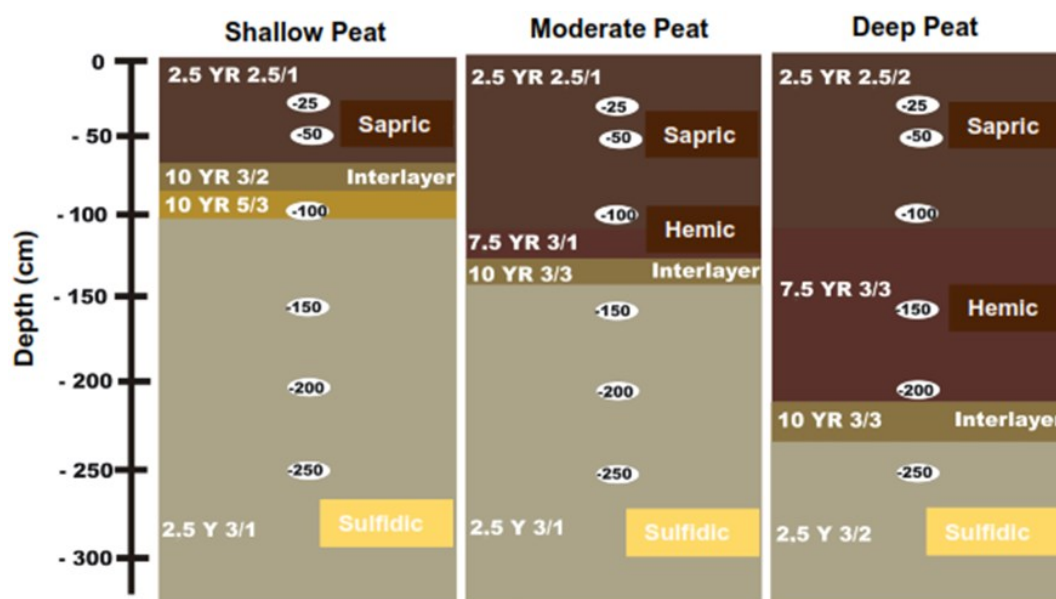
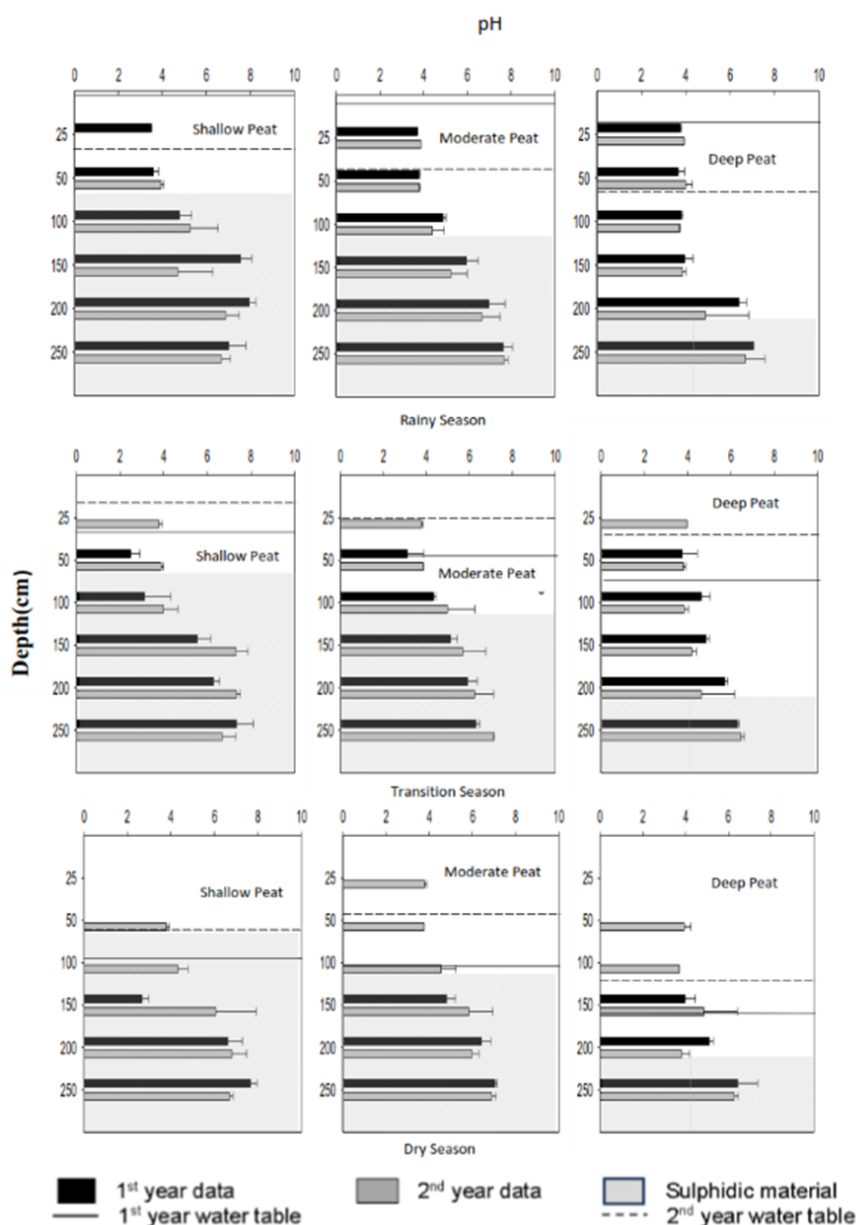


Figure 2. Cross-section of soil profile and peat water sampling points.



**Figure 3.** pH of peat at different peat thicknesses and seasons.

analyzer, 2 mL aliquots of all DOC samples were automatically acidified to pH 4 or less and sparged for 1.5 min to remove inorganic carbon.

Electric conductivity (EC) and pH of water were measured using conductometer “HI 8713” (HANNA Instruments, Austria) with a measurement error of 5% and WinLab® Data Line pH Measuring Instruments. The EC and pH of water samples were measured in the laboratory.

### 3. RESULTS AND DISCUSSIONS

#### 3.1. pH of Peat Water

The peat water in the peat layer was in an acidic condition at the three sampling times with a pH

range of 2.5–5.7 (Fig. 3). Meanwhile, in the sulfidic material layer, the pH of the water is higher. The same conditions were found in Kalampangan peat water, with a pH range of 3.68–4.31 [30], Lahei peat water with a pH range of 3.83–3.90 [31], and the pH of the black water of the Siak River, Sumatra, is in the range of 4.4–4.7 [22]. The high acidity of the water in the peat layer is influenced by two factors: the process of decomposition of the peat, through organic acids [32] and the diffusion of  $H^+$  ions resulting from the oxidation of the sulfidic material underneath [33].

During the rainy season, the pH of the organic layer water in the three peat thicknesses ranges from 3.5 to 6.4. The acidity of the peat layer drops

to 2.5–5.7 during the transition season and ranges from 3.7–5.1 during the dry season. The decrease in water pH also occurs in the sulfidic material layer where the water pH ranges from 4.7 to 7.9 during the rainy season. While in the transition and dry seasons, the pH of the water ranges from 3.1 to 7.3 and 2.67 to 7.65. Higher water acidity in the dry season compared to the rainy season was also reported by research conducted by Anda et al. [34] on the peatlands of Palingkau and Dadahup, Central Kalimantan. Observations in the canals showed that the lowest water pH and the highest concentration of dissolved ions occurred during the dry season, indicating pyrite oxidation, which then exited through the drainage.

The difference in peat water pH between the dry season and the rainy season is thought to be due to the dilution effect of rainwater. The large amount of water in the soil profile during the rainy season is thought to have a dilution effect on the concentration of  $H^+$  and  $Fe^{3+}$  ions, thus, increasing of peat water pH. The dilution effect during the rainy season also affects the pH due to the reduction of iron and manganese in the hydroxide form [35].

In this study, the pH of the peat water increases in line with the thicker of the peat layer (Fig. 3). In thin organic peat layers, the pH of peat water ranges from 2.9–3.9, while in moderate peat and deep peat, they are 3.1–4.8 and 3.7–6.4, respectively. Knorr et al. [36] also described the effect of peat layer

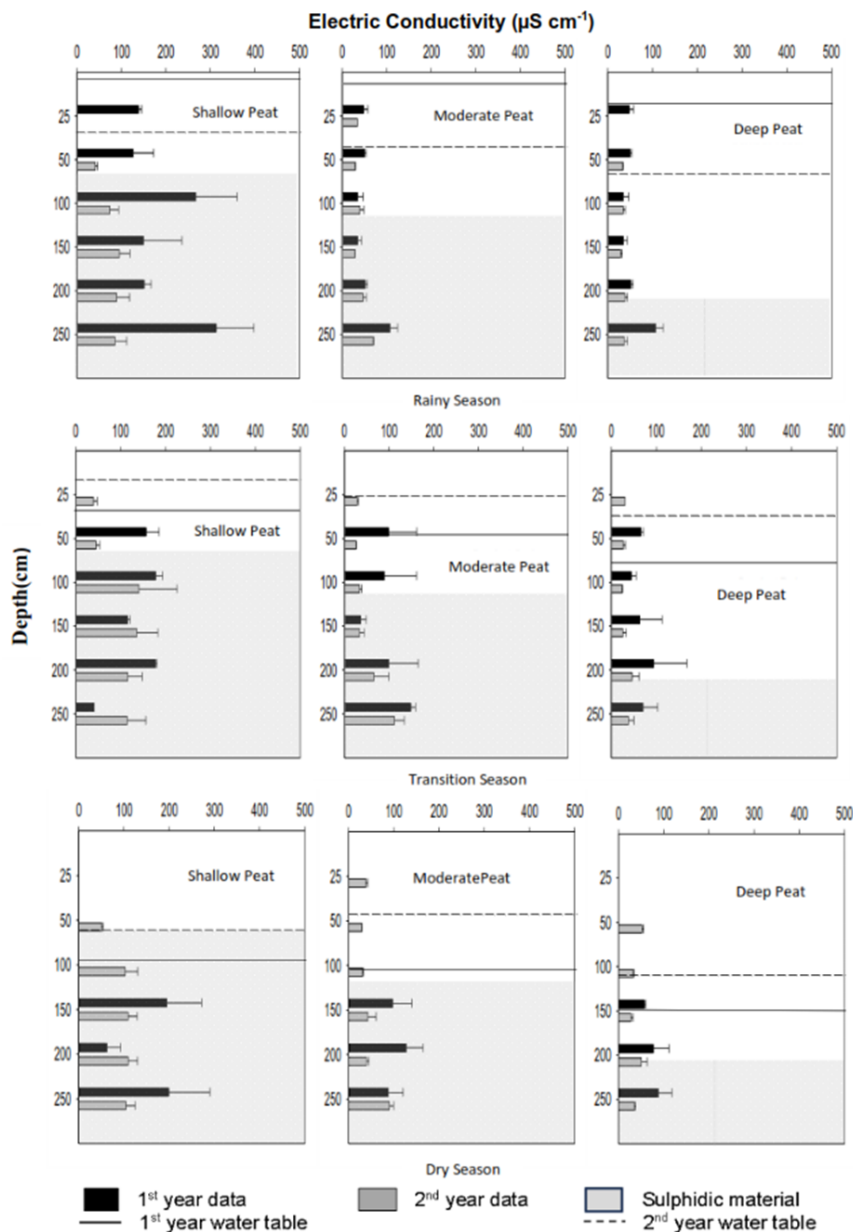
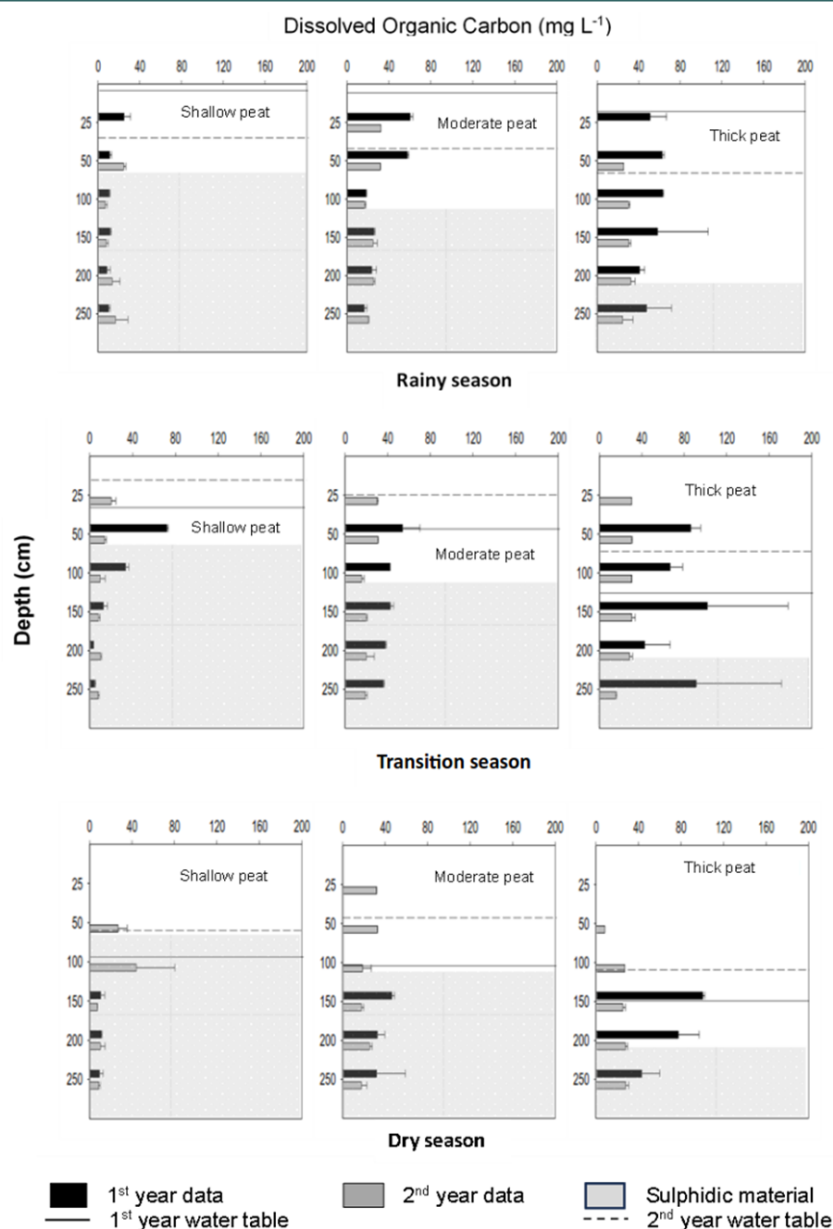


Figure 4. EC of peat at different peat thicknesses and seasons.





**Figure 5.** DOC concentrations of peat at different peat thicknesses and seasons.

thickness on the acidity of temperate climate peat water in Bavaria, Germany. The study stated that the concentration of dissolved hydrogen in thin peat water is greater than in moderate and thick peat water. The difference in hydrogen concentration between the three peat thicknesses is thought to originate from the oxidation reaction of pyrite (a sulfidic material) which is influenced by soil redox conditions. The contribution of hydrogen ions resulting from pyrite oxidation will be affected by the thickness of the peat layer. Anda et al. [34] compared the actual acidity of three Sulphemist peat profiles in Palingkau and Dadahup, Central Kalimantan, which had different depths of sulfidic material (20, 70 and 143 cm, respectively). The

results of this study indicate that peat with a thickness of 20 cm has increased acidity in the lower layer horizon compared to the upper layer, which indicates the presence of sulfidic material oxidation. In the other two soil profiles, there was no significant difference in acidity between the upper and lower layers of the horizon. Differences in acidity due to differences in peat thickness indicate a function of peat as a buffer for the decrease in acidity due to pyrite oxidation. The peat layer above the sulfidic material reduces the intensity of  $\text{Fe}^{3+}$  reduction or  $\text{FeS}_2$  oxidation through the chelation process of Fe and maintains a more reductive soil condition. The formation of complexes of Fe and organic acids also reduces the

intensity of the decomposition process which can produce  $H^+$  ions in the soil solution [37].

### 3.2. Electric Conductivity of Peat Water

The average EC of peat water ranges from 21 to 313  $\mu S\ cm^{-1}$  (Fig. 4). The EC value of peat water in this study was 2–20 times higher when compared to studies on peatlands in other locations. Haraguchi et al. [32] stated that for the peatlands of Lahei, Bakung, Rasau and Paduran (Sebangau Watershed, Central Kalimantan), EC values were 7.52–58.8, 11.03–55.90, 6.80–14.89, and 24.4–95.10  $\mu S\ cm^{-1}$ , respectively. The lower EC value (45–190  $\mu S\ cm^{-1}$ ) was also found in Sebangau river water [26].

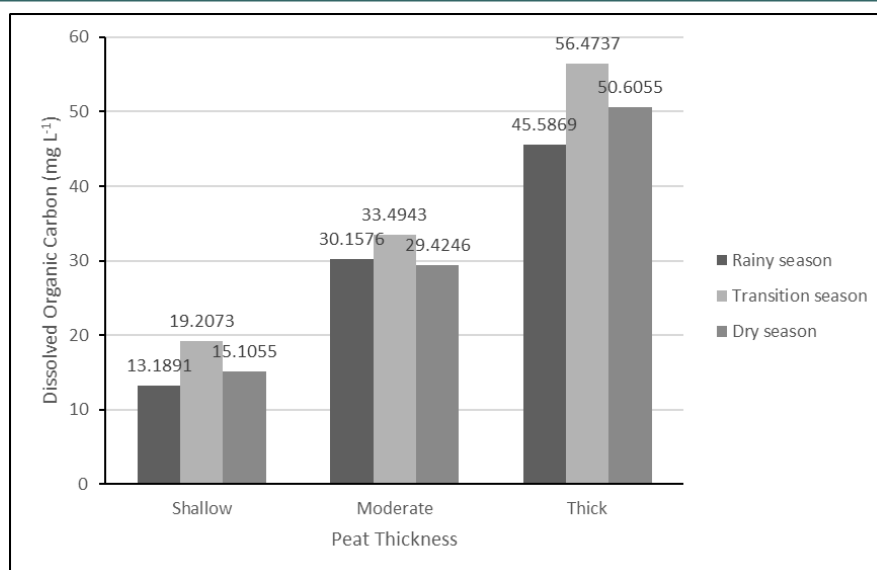
The peat layer has a lower EC value when compared to the sulfidic material. The EC values for the peat layer at each thickness ranged from 39–156  $\mu S\ cm^{-1}$  (shallow peat), 25–49  $\mu S\ cm^{-1}$  (moderate peat) and 24–94  $\mu S\ cm^{-1}$  (deep peat). Whereas in the sulfidic layer, the EC values were higher, namely 62–313  $\mu S\ cm^{-1}$  (shallow peat), 28–148  $\mu S\ cm^{-1}$  (moderate peat) and 35–107  $\mu S\ cm^{-1}$  (deep peat). The relatively low EC value in the top/peat layer is related to the low concentration of dissolved ions in the peat water [38]. Contrastly, higher EC values ( $> 200\ \mu S\ cm^{-1}$ ) in deeper layers (sulfidic materials) indicate higher concentrations of dissolved ions, which originate from the contribution of mineral ions (sulfidic materials). Comas et al. [39] mentioned that the increase in soil solution EC is related to the dissolution of

mineral materials that supply dissolved ions into the soil solution.

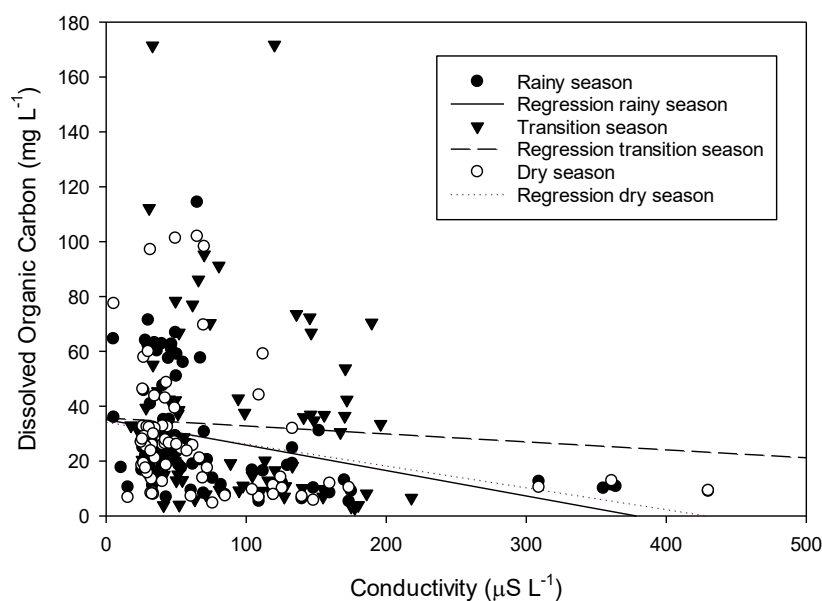
### 3.3. DOC Concentration

Average DOC concentrations of peat waters ranged from 3 to 101  $mg\ L^{-1}$  (Fig. 5). This DOC value is two times higher when compared to the DOC measurement for peat water in Central Kalimantan which originates from the Tumbang Nusa [25], Bereng Bengkel area [40], the Kahayan and Sebangau rivers [23][26]. DOC measurements of peat water show that the highest concentration is found in deep peat during the rainy season, dry season, and the transition from the rainy season to the dry season (Fig. 6). The difference in concentration between the three locations is due to differences in the organic layer thickness. Aitkenhead-Peterson et al. [41] explained that the organic layer is a source of dissolved organic matter, which is allochthonous in water. The release of DOC from peat materials depends on the content of organic matter and the degree of decomposition [26][42]. The degree of decomposition that has not yet been advanced in deep peat indicates that the abundance of fresh plant residue is still high, so the decomposition process of organic matter (peat) is still intensively running, and the release of DOC is also high.

The difference in DOC concentration can be related to the acidification on shallow peat due to pyrite oxidation below the organic horizon, which

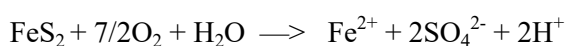


**Figure 6.** The average balance of dissolved organic carbon in peat water at different thicknesses and seasons.



**Figure 7.** The relationship between electrical conductivity (EC) and dissolved organic carbon (DOC) in peat water (coefficient correlation ( $r$ ) of rainy season = 0.25, and  $r$  of dry season = 0.38).

reflects from decreasing of peat water pH in line with the diminishing of peat layer in soil profiles (Fig. 3). The effect of pH on DOC concentration in water has been known from studies in other areas, such as Ishikawa et al. [23] on the Sebangau River, Knorr [36] on surface water in swamps in Germany, and Ewa et al. [43] in Polish peat groundwater. The relationship between acidity and DOC concentration is thought to be due to: a decrease in pH will increase the protonation of organic acid and thus that suppression of organic matter solubility [44] and an increase in anion concentration acids such as sulfates and nitrates are produced by oxidative reactions, which in turn lead to decreased DOC solubility and precipitation [16][45][46]. Ion sulfates can be produced by oxidative of sulfidic (pyrite) material below the organic layer as described in this equation [34]:



The difference in DOC concentration between peat thickness is also closely related to the electrical conductivity of the peat water, which reflects the concentration of dissolved hydraulic salts and ionic strength of peat water. The results showed a negative correlation between EC and DOC concentration, as depicted in Figure 7. The negative correlation was significant in the observation of the rainy ( $r = 0.25$ ) and dry seasons ( $r = 0.38$ ), while in

the transitional season, it was not significant. A negative correlation between EC and DOC concentration has been reported by previous studies [22][26][47][48]. High electrical conductivity followed by an increase in ionic strength reduces the solubility of DOC [16][46]. At high EC values and ionic concentrations, organic matter coagulation occurs through the cation bridge mechanism [49][50]. Data from this study show that shallow peat has higher electrical conductivity than moderate peat and deep peat (Fig. 3b) [51]. The low DOC solubility in shallow peat is one of the causes of the low DOC concentration compared to deep and moderate peat. The DOC concentration between the three sampling times showed a clear difference. This difference indicates the influence of seasonality and hydrological conditions on DOC concentration. Volk et al. [52] stated that dissolved organic matter content is a seasonality and rainfall function. At the same depth, DOC concentrations during the transition and rainy seasons are lower than those during the dry season. This high concentration of DOC may not be the only link to a higher production of DOC but also to a relative concentration of it, due to a lesser dilution and water flow observed during the dry season [16]-[19]. In these conditions, DOC production is high due to increased aerobic decomposition of the peat material when the water level falls and the temperature increases [53]-[55]. In aerobic



conditions, the activity of phenol oxidase (an enzyme that breaks down phenol compounds) and  $\beta$ -glucosidase increases [53] which indicates the presence of carbon mineralization, and then DOC production also increases [56]. The DOC concentration in the rainy season decreased from more than 100 to 60 mg L<sup>-1</sup> at a depth of 150 cm deep peat, while on moderate peat it decreased from 45 to 25 mg L<sup>-1</sup> at the same depth. A decrease in DOC concentrations during the rainy season was also reported by Baum et al. [57] on the Siak River water. The decrease in DOC concentration was in line with the increase in precipitation at the end of the rainy season (March) which led to loss of DOC through leaching processes.

Furthermore, Clark et al. [58] stated that there was a negative relationship between flow rate and DOC concentration due to the dilution effect during the rainy season. This decrease in DOC concentration is caused, in the rainy season, by the quick leaching of DOC products and under certain conditions can result in dissolution [59] or carried through underground flow (groundwater) [18]. There is a decrease in contact time between the solid and solution phases during the rainy season, resulting in DOC transfer from the top layer to the bottom layer [60]. The research conducted by Selberg et al. [61] in the Pitkjärvi Peat Lake (Estonia) showed a fivefold decrease in DOC concentration due to the dissolving process during the rainy when compared to the dry season. Besides, in the fast flow of water during the rainy season, the addition of dissolved organic compounds cannot occur due to flushing in the peat layer, especially thin peat either through percolation or surface runoff [19][61]. The DOC concentration indicates the loss of DOC through surface runoff, percolation, and underground flow during the rainy season at a watershed outlet. Hernes et al. [62] stated an increase in DOC concentration with the increasing discharge (Q) of the Willow Slough Watershed, California, during the rainy season.

The DOC measurement results showed that, in general, the concentration in the upper layer was higher than that of the layer below and the sulfidic material. Funakawa et al. [63] suspected that this phenomenon is due to the continuous degradation of organic matter in the top layer of peat soil.

Besides, the low DOC concentration in the lower layer is closely related to the peat water's pH and the redox conditions that affect the retention of DOC by the mineral substratum below the peat layer. In high content of organic matter, the pH factor of groundwater plays a role in the leaching of DOC, high levels of soil and water acidity will suppress DOC leaching [25].

#### 4. CONCLUSIONS

The results showed that DOC was simultaneously influenced by the thickness of the peat, the depth of the surface of the sulfidic material layer, and the water table's condition. Deep peat releases higher DOC than shallow and moderate peat. DOC concentration in the dry season is higher than in the rainy and transitional seasons. The difference in DOC concentration between peat thicknesses is also related to the electrical conductivity of the peat water. The results showed a negative correlation between EC and DOC concentration. The negative correlation was significant in the observation of the rainy and dry seasons, while in the transitional season, it was not significant.

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Conceptualization, Z. D. and B. R.; Methodology, Z. D.; Software, Z. D.; Validation, Z. D. and A. J.; Formal Analysis, Z. D.; Investigation, Z. D.; Resources, Z. D. and B. R.; Data Curation, Z. D.; Writing – Original Draft Preparation, Z. D.; Writing – Review & Editing, C. A.; Visualization, Z. D.; Supervision, B. R.; Project Administration, B. R.; Funding Acquisition, B. R.

## Conflicts of Interest

The author(s) declare no conflict of interest.

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